3. The dispersion curve for non-luminous thallium vapour indicates the existence of anomalous dispersion at the wave-lengths $\lambda = 5350{\cdot}65$ Å.U., and probably also at or near the wave-length $\lambda = 6000$ Å.U.

In conclusion, I desire to express my great appreciation of the help given me by my students, Messrs. H. Grayson Smith and L. W. Rentner, in taking the readings, and to that given me by my assistant, Mr. R. H. Chappel, in making up the interferometer tubes and prisms.

On the Emission and Absorption Spectra of Mercury.

By Prof. J. C. McLennan, F.R.S., and W. W. Shaver, M.A., University of Toronto.

(Received June 29, 1921.)

[Plate 7.]

1. *Introduction.*

In two papers by Raymond C. Dearle* accounts are given of investigations in which a special study was made of the monochromatic radiation $\lambda = 1{\cdot}014\mu$. This radiation Paschen† found to be by far the strongest in the emission arc spectrum of mercury, and Dearle's observations corroborated this view.

Dearle found moreover, that when light of this wave-length was passed through non-luminous mercury vapour, even when of low density, a definite and well-marked absorption was obtained. He also found the same effect when the mercury vapour traversed was in direct contact with the mercury vapour in which the arc was established from which the original radiation was obtained, and was also directly illuminated by the radiation from this arc.

It is well known that the radiations whose frequencies are given by $\nu = (1{\cdot}5, \mathrm{S}) - (2, p_2)$, *i.e.*, $\lambda = 2536{\cdot}72$ Å.U. and $\nu = (1{\cdot}5, \mathrm{S}) - (2, \mathrm{P})$, *i.e.*, $\lambda = 1849{\cdot}6$ Å.U. are strongly absorbed by non-luminous mercury vapour, but no one as yet has been able to confirm the observations made by Dearle that the radiation $\nu = (2, \mathrm{P}) - (2{\cdot}5, \mathrm{S})$, *i.e.*, $\lambda = 1{\cdot}014\mu$ is absorbed by mercury vapour which is not luminous.

It is quite clear from the application of the quantum theory made by Bohr

* Dearle, 'Roy. Soc. Proc.,' A, vol. 92, p. 608 (1916); vol. 95, p. 280 (1919).

† Paschen, 'Ann. der Phys.,' vol. 27 (13), p. 559 (1908).

to the problem of the origin of radiation that if mercury vapour were illuminated by radiation of frequency $\nu = (1{\cdot}5, S)-(2, P)$, *i.e.*, $\lambda = 1849{\cdot}6$ Å.U., a certain number of the atoms of mercury in the vapour would have the configuration of their constituent extra-nuclear electrons so modified that they would be in the condition to absorb the wave-length $\lambda = 1{\cdot}014\,\mu$; but in the absence of illumination by radiation of the wave-length $\lambda = 1849{\cdot}6$ Å.U., or of excitation of the mercury vapour by an equivalent stimulus, it is not clear how absorption of a radiation of the wave-length $\lambda = 1{\cdot}014\,\mu$ by the mercury vapour could be obtained. If the effect observed by Dearle was correctly interpreted by him, it would mean that the atoms of ordinary mercury vapour would have in addition to the well-established resonance potential of 4·9 volts, corresponding to $\lambda = 2536{\cdot}72$ Å.U., an additional one of 1·26 volts, corresponding to $\lambda = 1{\cdot}014\,\mu$.

Although extensive investigations have been made on the resonance and ionisation potentials of many of the elements, there appears to be very little evidence obtainable from them which would go to support the suggestion put forward by Dearle that ordinary unexcited mercury atoms are really characterised by the two resonance potentials mentioned. Mercury atoms which have absorbed the radiation $\lambda = 1849{\cdot}6$ Å.U. could, on the Bohr theory, possess the resonance potential 1·26 volts, but not mercury atoms whose electronic systems are in their ordinary stable configurations, provided views of the origin of radiations which are generally held at present remain valid.

As the suggestion put forward by Dearle as a result of his observations is of fundamental importance in connection with theories of atomic structure it was decided to set in train two lines of investigation with the object of clearing up the matter if possible. One of these investigations was undertaken by one of the authors of the present communication, and the second by the other. In the first investigation the photographic method was used, and in the other the method adopted involved the use of the spectrophotoelectric thalofide cell recently discovered by T. W. Case.*

In both of the investigations no evidence was obtained of any measurable absorption of radiation of the wave-length $\lambda = 1{\cdot}014\,\mu$ by non-luminous mercury vapour. In the case of luminous mercury, however, an easily measurable absorption of radiation of this wave-length was obtained when a thalofide cell was used to measure the intensities of the radiation.

* T. W. Case, 'Phys. Rev.' [2], vol. 15, p. 289 (1920); also U.S. Patents Nos. 1301227 and 1316350 for a light reactive resistance.

THE PHOTOGRAPHIC METHOD, by Prof. McLennan.

1. *Infra-red Photography.*

From the recently published accounts of the brilliant investigations carried out by Meggars,* Kiess,† and Merrill,‡ it became abundantly clear that by the use of photographic plates stained with the dye dicyanin it was possible to photograph spectra as far as $\lambda = 11650$ Å.U., and possibly beyond this limit.

As no photographs appeared to have been taken of the spectrum of mercury by these or other investigators with dicyanin-stained plates it appeared worth while attempting to take them. Considerable difficulty was experienced in obtaining dicyanin of good quality, but through the kindness of Dr. C. K. Mees of the Eastman Kodak Company some was finally obtained which enabled us to photograph spectra well up to the limit mentioned above.

2. *Photographic Results with Emission Spectra.*

Before proceeding to photograph the spectrum of mercury, it was considered best, in order to gain familiarity with the technique of the various operations, to make a study of the spectra of a number of the elements already investigated by Meggars and Kiess. In this work various types of plates were tried out, with both prism and grating spectrographs, the source of light being either a strong arc between metal electrodes or between carbon electrodes filled with salts of the various metals. In the case of mercury, ordinary commercial glass mercury-arc lamps, and also quartz mercury-arc lamps, were used.

With exposures up to six hours' duration, and a fairly fine spectograph slit, the limit of Wratten and Wainwright panchromatic plates with moderate exposures was found to be about $\lambda = 7000$ Å.U., and that of Ilford red sensitive plates about $\lambda = 7500$ Å.U. When ordinary rapid Seed dry plates, made by the Canadian Kodak Company, stained with dicyanin were used, spectra of moderate intensity were obtained, with a fine slit up to slightly over 10000 Å.U., with 12–17 hours' exposure. With a wide slit and 32 hours' exposure, spectra were obtained quite readily up to 11137 Å.U., with indications that in the case of very strong radiations this limit would be considerably extended.

The reproductions shown in (1), Plate 7, were obtained in photographing the

* Meggars, 'Bulletin of the Bureau of Standards,' vol. 14, p. 371 (1917).

† Kiess and Meggars, 'Bulletin of the Bureau of Standards,' No. 324, p. 637 (1918); and No. 372, p. 51 (1920).

‡ Merrill, 'Bulletin of the Bureau of Standards,' No. 318, p. 487 (1918).

spectrum of the mercury arc in the near infra-red, and those in (2), when an attempt was made to extend the spectrum of mercury as far into the infra-red as possible. In obtaining (1) a quartz mercury-arc lamp was used, which was operated with a current of about three ampères under a potential difference of about 40 volts. The slit used was wide, about $1\frac{1}{2}$ mm., and the exposure was about 32 hours. The spectrum was of the first order, the over-lapping portions of the higher orders being cut off by the use of a Wratten-Wainwright filter No. 22.

With the setting of the grating adopted in obtaining the spectrogram (*a*), (2), the wave-length $\lambda = 10140$ Å.U. came, as the reproduction shows, somewhat near the end of the plate. A new setting of the grating was therefore made, which brought this wave-length somewhat more to the right of the plate. An exposure of 17 hours' duration was then made, with the lamp running under the same conditions as before, and with the same filter inserted. In this case, however, the slit was made about one-half as wide as it was in taking the first plate. The spectrogram obtained is that designated as "*b*," (2).

Reproduction "*a*," (2), shows that the radiation of wave-length $\lambda = 10140$ Å.U. came out as a strongly marked diffuse wide band. The over-exposure was, however, too great to bring out the actual structure of the band. The plate from which reproduction "*b*" was taken was rather under-exposed, but in the original $\lambda = 10140$ Å.U., though faint, could be seen quite definitely, either as a band about 60 Å.U. in width, with inversion at the centre over a range of about 20 Å.U., or a doublet with about 35 Å.U., or about 40 Å.U. separation between centres. In the reproduction the detail is not clear. The fact, as the reproduction shows, that wave-lengths slightly above and slightly below $\lambda = 10140$ Å.U. came out clearly on the plate, rather points in the direction of inversion.

In reproduction "*c*," (3), which will be referred to later, the detail came out more definitely than in either "*a*" or "*b*." There it will be seen there is a strongly marked band at $\lambda = 10217$ Å.U., a less strongly marked one at $\lambda = 10165$ Å.U., and a fainter and narrower one at $\lambda = 10121$ Å.U. The latter two would appear to make up what has hitherto been taken to be the wave-length $\lambda = 10140$, and the existence of the third strong band close to them at $\lambda = 10217$ Å.U. would account for the strongly marked diffuse wide band shown in "*a*."

On measuring up the spectrograms of the mercury spectrum, it was found that wave-lengths were obtained up to $\lambda = 11137$ Å.U., a number being recorded which had not been observed. These are given in the list collected in Table I, and are considered to be correct to 1 Å.U. The results obtained

by Wiedemann* and by Stiles,† which appear to be the most complete hitherto recorded in the range covered by the present observations, are also given in the Table.

Table I.—Wave-Lengths from Mercury Arc.

Relative intensities.	Observer.		
	The Author.	Wiedemann.	Stiles.
	Å.U.	Å.U.	A.U.
8	6908	6907·776	6907·74
	—	7044	—
10	7082·92	7082·273	7081·96
10	7092·46	7092·456	
	—	7122	
2	7179	7179	
1	7295	7295	
1	7371	7371	
2	7453	7453	
2	7551	7551	
2	7606	7606	
3	7673	7676	
8	7729·46	7729·456	
3	7821	7821	
2	7992	7982	
2	8028	—	
2	8077	8077	
1	8104	—	
1	8145	—	
3	8164	8164	
3	8198	8198	
1	8665		
1	8730		
1	8774		
1	8798		
1	8832		
1	9025		
1	9057		
3	9217		
3	9255		
3	9288		
1	9327		
1	9439		
1	9487		
1	9510		
1	9565		
1	9597		
1	9628		
1	9710		
1	9753		
2	9914		
2	9953		
2	9993		
2	10037		
2	10078		
30 {	10121 } 10140		
	10165 }		

* Wiedemann, 'Ann. der Phys.,' vol. 38, p. 1041 (1912).

† Stiles, 'Astrophysical Journal,' vol. 30, p. 48 (1909).

Table I—(*contd.*)

Relative intensities.	Observer.		
	The Author.	Wiedemann.	Stiles.
	Å.U.	A.U.	A.U.
3	10217		
1	10301		
4	10344		
6	10377		
6	10416		
6	10453		
3	10485		
3	10531		
2	10567		
1	10845		
1	10874		
1	10883		
4	11053		
4	11088		
4	11101		
4	11137		

It will be seen that, in all, some forty-four new wave-lengths in the spectrum of mercury have been identified photographically. Of these, $\lambda = 1{\cdot}038\,\mu$ and $\lambda = 1{\cdot}045\,\mu$, respectively, had been previously observed by McLennan and Dearle,* and by Moll,† with a radiometric method involving the use of a linear thermocouple.

It may be that some of the wave-lengths given in the list are merely ghosts, for, in taking spectrograms with the same grating in the visible region, several of the strong lines in the spectrum of mercury were accompanied by them. Apart from this possible defect, however, the results are interesting, as showing that the wave-lengths of the radiation emitted by a luminous mercury vapour can be photographically recorded at least as far as $\lambda = 11137$ Å.U., and that we have in this way a new means of investigating the character of such important radiations as $\lambda = 10140$ Å.U., and of studying their specific properties.

3. *Absorption Experiments.*

In carrying out the absorption experiments, the procedure followed and the optical arrangements made, were, with one exception, identical with those adopted in obtaining the photograph of the emission spectrum of mercury, shown in reproduction "*a*," (2). The exception mentioned

* McLennan and Dearle, 'Phil. Mag.,' vol. 30, November, 1915, p. 683.

† Moll, 'Kon. Akad. Wet. Amsterdam, Proceedings,' vol. 9, p. 544 (1907).

consisted in the insertion of a highly exhausted glass tube, 2·5 cm. in diameter, immediately in front of the slit.

A photograph was taken of thirty-two hours' duration, with this tube partly filled with mercury, and heated by an electric furnace to 300° C. In this case the tube was adjusted in position, so that the surface of the mercury was just below the bottom of the slit. At the temperature used it will be seen that the density of the mercury vapour traversed by the light was at least as high as that used in the experiments by Dearle.

A reproduction of part of the plate obtained in this case is shown in "*c*," (3). Accompanying it there is shown the corresponding portion of reproduction "*a*," (2). Through some stray light reaching it, either when in the spectrograph or in the developing room, the plate was slightly covered with a thin fog. It shows, however, quite definitely the wave-length $\lambda = 10140$. It is true this wave-length does not come out as a strongly marked broad band as in "*a*," but the difference was no doubt due to a part of the impinging light being reflected from or absorbed by the glass walls of the absorption tube.

It seems clear from the reproduction that there was little, if any, absorption by the mercury vapour in the absorption tube. If any absorption by the vapour did take place, it was extremely small compared with what one readily obtained with radiation of wave-lengths $\lambda = 2536{\cdot}72$ Å.U. and $\lambda = 1849{\cdot}6$ Å.U. It is true that the absorption of $\lambda = 10140$ Å.U. obtained by Dearle with non-luminous mercury vapour was only partial, but it was sufficiently well defined, according to his curves, to expect some indication of it on our photographic plates, if what he observed was a real absorption effect.

In so far, then, as these experiments go, they show that non-luminous mercury vapour does not absorb the radiation $\lambda = 10140$ Å.U. to the extent of appreciably weakening the photographic record of this wave-length.* It would follow, then, that mercury atoms, with their electronic systems in their ordinary undisturbed state, do not have a resonance potential of 1·26 volts, and that therefore the true resonance potential for mercury atoms is the well established one, and corresponding to the quantum equivalent of $\lambda = 2536{\cdot}72$ Å.U., *i.e.*, to about 4·9 volts.

A number of wave-lengths were recorded on "*c*," (3), which were not strongly marked on either "*a*" or "*b*" of (2). Their values are given on the plate, and are also included in the list given in Table I.

* From a note in 'Nature' of April 14, 1921, p. 203, the writer has just learned that the spectrum of mercury vapour has been recently photographed by A. Terenin up to $\lambda = 11300$ Å.U. In this investigation there was found no absorption by non-luminous mercury vapour of the radiation of wave-length $\lambda = 10140$.

The writer wishes to take this opportunity of expressing his appreciation of the help he received in making the optical arrangements, and in taking the photographs, from his research assistant, Mr. Vladimir Lubovich, of the University of St. Petersburg.

Thalofide Cell Experiments. By W. W. Shaver.

1. *The Cell and its Properties.*

The thalofide cell used in these experiments was invented by and obtained from T. W. Case,* of the Case Research Laboratory, Auburn, New York. The active part of this cell is a preparation of thallium-oxy-sulphide, fused on the surface of a quartz plate, the latter being securely mounted within an evacuated cylindrical glass flask, about 2·5 cm. in diameter. Evacuation was found to increase the sensitivity of the cell and to prevent deterioration through oxidation. The cell is photo-electrically sensitive in the near infra-red region from $\lambda = 6000$ Å.U. to $\lambda = 12000$ Å.U. The sensitivity curve, as given by Coblentz,† shows a sharp rise from $\lambda = 6000$ Å.U. up to $\lambda = 9000$ Å.U., and then a further rise to $\lambda = 10000$ Å.U. From this wave-length on the sensitivity falls off rapidly, and is practically *nil* at 12000 Å.U.

The photo-electric sensitivity of this cell consists in a lowering of the electric resistance of the active preparation when it is exposed to radiations comprised within the limits mentioned. As the cell has its maximum sensitivity at or near $\lambda = 10000$ Å.U., it was thought that it might prove specially suitable for studying radiation from mercury vapour of wave-length $\lambda = 10140$ Å.U., and some preliminary experiments showed this conjecture to be well warranted.

The following is a short account of some experiments involving the use of this thalofide cell, and arranged with the object of investigating whether or not $\lambda = 10140$ Å.U. is absorbed by non-luminous and by luminous mercury vapour. It may be stated here that the results of the investigation go to show that λ 10140 Å.U. is not appreciably absorbed by non-luminous mercury vapour, but that it is absorbed to a marked extent by mercury vapour in which an arc of low intensity is maintained.

2. *Sensitivity Measurements.*

In commencing the investigation, some observations were made on the sensitivity of the cell when activated by light from a carbon-filament incandescent lamp, and by that from a quartz mercury arc lamp. Following

* Case, 'Phys. Rev.,' 1920, p. 289.

† Coblentz, 'Bureau of Standards,' Washington, No. 380, p. 253 (1920).

the instructions given by Paschen,* Wratten filters Nos. H. 45 and F. 29, together with a water cell 1 cm. in thickness, were used to confine the light falling on the cell to the range of wave-lengths lying between $\lambda = 8500$ Å.U. and $\lambda = 15000$ Å.U. As the sensitivity of the cell is practically zero for $\lambda = 12000$ Å.U., this arrangement resulted in the effective wave-lengths being necessarily limited to those between $\lambda = 8500$ Å.U. and $\lambda = 12000$ Å.U. Within this range the radiation of wave-length $\lambda = 10140$ is, according to the observations of Dearle, by far the strongest in the light emitted by the mercury arc, and consequently in what follows it has been assumed that the effects obtained when the light from the mercury arc was used may be considered as being ascribable to the radiation $\lambda = 10140$ Å.U. In these experiments, with a carbon filament lamp of 32 candle-power, and a mercury-arc lamp, the former was placed at a distance of about 132 cm., and the latter at a distance of about 40 cm., from the active surface of the cell. The cell was joined in a series with a resistance of 240,000 ohms, a Tinsley galvanometer of 4000 ohms resistance and a storage battery having a potential difference of 4·72 volts. Readings were taken in millimetres on a scale at a distance of 1 metre from the galvanometer, and the sensitivity of the latter was such as to give 240 mm. deflection at 1 metre per microampère.

The unilluminated thalofide cell was found to give with this circuit a steady so-called "dark current" of 135 mm. deflection, but when the cell was illuminated this deflection was increased by an amount which depended on the intensity of the activating radiation as determined by the energy consumed by the source. Tables I and II contain the values of these added deflections, together with the corresponding amounts of energy supplied to the lamps.

Table I.—Carbon Filament Lamp

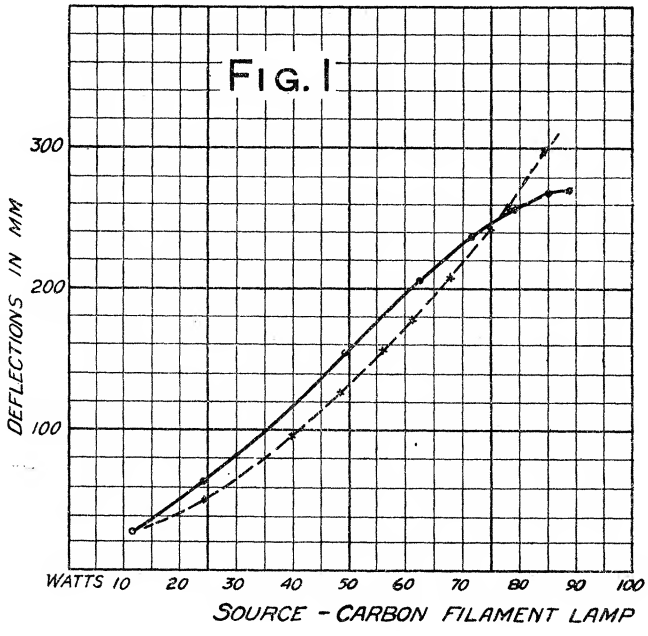
Source energy.	Increase in galvanometer deflection.	Source energy.	Increase in galvanometer deflection.
watts.	mm.	watts.	mm.
89·4	267	39·9	98
85·1	267	47·9	126
79·2	256	56·6	157
72·2	238	61·2	178
63·4	205	67·6	208
49·9	155	75·3	242
24·4	63	77·9	259
11·2	27	84·3	295
24·1	51		

* Paschen, 'Wied. Ann.,' No. 43, p. 858 (1914).

Table II.—Mercury Arc Lamp.

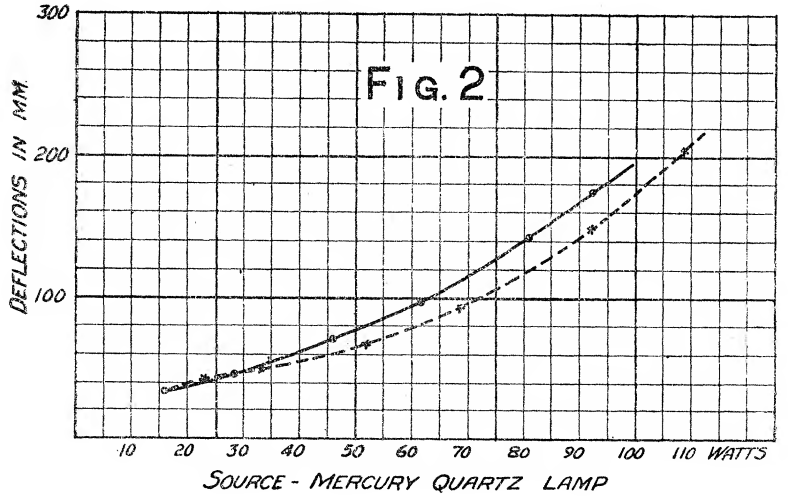
Source energy.	Increase in galvanometer deflection.	Source energy.	Increase in galvanometer deflection.
watts.	mm.	watts.	mm.
110·0	164	16·0	37
123·2	232	23·0	43
92·5	174	33·0	50
80·5	143	51·3	68
62·4	97	68·7	94
45·5	71	92·0	147
28·6	48	108·1	205

In figs. 1 and 2 graphs are drawn corresponding to the numbers in the Tables, the continuous curve representing the deflection obtained with a decreasing supply of energy and the broken one representing those obtained as the energy supplied to the lamp increased.



As the cell did not reach a steady state at once when being exposed to the radiation, all the readings were taken one minute after the commencement of each exposure. The lag shown by the curves was obtained when both lamps were used, and although it is known that it takes a considerable time for the quartz mercury arc lamps to settle down into a steady state after they are set in operation, it is thought that sufficient time was allowed after starting the

lamp for the steady state to be reached and that, therefore, the lag observed should be connected up, in the main, with the functioning of the thalofide



cell. From the values given in the Table it will be seen that under illumination an increase in current was easily obtained of twice the amount of the original "dark current."

3. *Preliminary Absorption Experiments.*

In these experiments the quartz mercury arc lamp was used as the source of radiation and the thalofide cell was provided with the filters mentioned in Section 2, the light being admitted to the cell through a slit about 2·5 mm. in width. When the lamp had reached a steady state and the galvanometer in series with the thalofide cell showed a steady deflection due to the illumination of 136 mm., an empty thin-walled pyrex glass bulb about 9 cm. in diameter was placed between the lamp and the filters. This produced a drop in the galvanometer deflection of 22 mm., due to reflection from or adsorption by its walls. A quantity of mercury was then placed in the bulb which was afterwards exhausted, hermetically sealed, and as previously, placed in the same position in the path of the light, care being taken to see that no mercury adhered to the walls of the bulb. In this case the fall in deflection due to the insertion of the bulb was practically the same as that obtained when it was empty. Heat was next applied to the bulb by means of an electric furnace and at the same time the walls of the bulb at the points of entrance and exit of the light were heated directly with auxiliary Bunsen burners, in order to present any deposit taking place from the mercury vapour. This was found to be necessary as it was observed that even a slight and scarcely

visible deposit of condensed vapour on the bulb walls immediately produced a marked decrease in the galvanometer readings.

In one particular set of readings with the mercury bulb at 24° C. an added deflection due to illumination of 151 mm. was obtained. When the bulb was heated to 350° C. the added deflection obtained was 152·5 mm. The consumption of energy by the lamp was checked during heating and it was found not to vary more than 1 per cent. From this it seemed clear that practically no absorption of the illuminating radiation took place. As mentioned above, the active radiation was confined to wave-lengths between $\lambda = 8500$ Å.U. and $\lambda = 12000$ Å.U., and as $\lambda = 10140$ Å.U. was in all probability the most intense radiation in this range it seemed fair to conclude from these experiments that this wave-length was not appreciably absorbed by non-luminous mercury vapour.

4. *Absorption Experiments with Non-luminous Mercury Vapour.*

(*a*) A series of experiments was then made with the activating radiation confined entirely to the wave-length $\lambda = 10140$ Å.U. With the grating used in the experiments described in the first part of this paper, it was possible to locate with precision from measurements on the photographic plates, the exact position of $\lambda = 10140$ Å.U. The thalofide cell was therefore mounted in a tube attached to a plate which fitted into the grooves of the plate holder so that it could be moved along the focal plane of the grating. The slit of the spectrograph was widened to about 1·5 mm., and a second slit of 4 mm. width was placed immediately in front of the thalofide cell to limit the radiation which could enter the latter from the grating. The light from a mercury arc lamp was projected on the slit of the spectrograph after passing through a Wratten filter No. 22, inserted to cut off the green, violet and ultra-violet radiation of the second order spectrum. The plate carrying the thalofide cell was then moved along the grooves in the focal plane to the point previously determined as the position of the focussed radiation of wave-length $\lambda = 10140$ Å.U. As soon as this position was reached, a large increase in the galvanometer deflection was at once obtained, and it was interesting to observe how accurately this wave-length could be located by the use of the thalofide cell. Movements of the latter in the focal plane in either direction were immediately followed by the disappearance of the galvanometer deflection in excess of that due to the "dark current."

When it was found that large readings could be readily obtained with the thalofide cell when the radiation was limited to the wave-length $\lambda = 10140$ Å.U., an experiment was made to test the absorption of this particular wave-length by non-luminous mercury vapour.

The pyrex glass mercury vapour absorption tube used in the photographic experiments was mounted in the electric furnace and placed in front of the spectrograph slit in the path of the light from the mercury arc. This produced a drop in the galvanometer deflections of 30 mm., when the reading due to the direct radiation was 105 mm. The tube was then heated to 300° C., and the galvanometer readings were noted as the temperature of the vapour tube rose. No difference was observed in the galvanometer readings, the deflection being still 75 mm. when the temperature of 300° C. was reached. At this temperature it will be noted that the density of the mercury vapour was that corresponding approximately to atmospheric pressure. This experiment was repeated with a 300-watt argon-filled tungsten lamp as the source of radiation, and in this case also no absorption by the mercury vapour was observed.

(*b*) To make a more exacting test for absorption than that made in the previous experiment, two absorption tubes of pyrex glass, of exactly the same dimensions, 24·4 cm. in length and 2·5 cm. in diameter, were constructed with plane parallel plate windows cut from the same sheet of glass. Some mercury was put into one of the tubes, and then both were highly exhausted and hermetically sealed. The windows of the mercury tube were kept absolutely free from condensed vapour by being gently warmed by a heating circuit of nichrome wire wound about the two ends. The mercury absorption tube was mounted between the source of radiation and the spectrograph slit in such a way that it could readily be removed and the empty tube placed in an exactly similar position. Having obtained the "dark current" galvanometer deflection, the light from the source was allowed to fall on the spectrograph slit, after passing through the absorption tube. The increase in galvanometer deflection was noted as soon as it became steady, and then the empty tube was quickly substituted for the absorption tube. The deflection was again taken, and in this way any change of galvanometer deflection due to the absorption of the radiation of wave-length $\lambda = 10140$ Å.U. by the mercury vapour could be determined immediately.

The following Tables give the results of a series of pairs of readings, using both the mercury-arc and the argon-filled tungsten lamp as sources of the radiation $\lambda = 10140$ Å.U.

From the Table it will be seen that when the mercury-arc lamp was used as the source of the radiation $\lambda = 10140$ Å.U., the average of the readings obtained with the empty tube was the same as that of those obtained with the tube which had the mercury in it. When the tungsten lamp was used as the source of the radiation, practically the same result was obtained, as

the slight difference in the mean of the readings for the two tubes (0·4 per cent.) was well within the limits of experimental error.

Table III.—Mercury-Arc Lamp.

Increase in galvanometer deflection when radiation of wave-length 10140 Å.U. was passed through		Increase in galvanometer deflection when radiation of wave-length 10140 Å.U. was passed through	
(*a*) Mercury absorption tube.	(*b*) Empty tube.	(*a*) Mercury absorption tube.	(*b*) Empty tube.
mm.	mm.	mm.	mm.
64	65	66	68
64	64	61	59
66	65	59	56
63	63	—	—
62	63	70	69
58	58	70	75
—	—	69	69
66	65	67	69
70	70	69	66
70	70	59	61
70	69		
Mean	...	69·1	69·1

Table IV.—Tungsten Lamp.

Increase in galvanometer deflection when radiation of wave-length 10140 Å.U. was passed through		Increase in galvanometer deflection when radiation of wave-length 10140 Å.U. was passed through	
(*a*) Mercury absorption tube.	(*b*) Empty tube.	(*a*) Mercury absorption tube.	(*b*) Empty tube.
mm.	mm.	mm.	mm.
134	137	144	138
144	136	130	137
137	137	130	135
135	137	141	132
139	136	132	135
Mean	...	136·6	136·0

This experiment, therefore, makes it very clear that the radiation $\lambda = 10140$ Å.U. is not absorbed to any appreciable extent by mercury vapour saturated at room temperature.

(*c*) A third experiment was made to test the absorption of $\lambda = 10140$ Å.U. by saturated mercury vapour of various densities. The sources of the

radiation were again the quartz mercury-arc lamp and the tungsten argon-filled one. The absorption tube was the one referred to in "(*b*)," which contained some mercury. This tube was placed within an electric furnace, whose temperature was gradually raised to 350° C. Over this range of temperatures several sets of readings were taken with each of the lamps. A set of readings, taken with the mercury-arc lamp, as the source of the radiation $\lambda = 10140$ Å.U. is given in Table V, and a set taken with the tungsten lamp is given in Table VI.

Table V.—Mercury-Arc Lamp.

Temperature of tube.	Increase in galvanometer deflection over that due to "dark current."	Temperature of tube.	Increase in galvanometer deflection over that due to "dark current."
° C.	mm.	° C.	mm.
25	71	233	76
65	86	245	76
105	74	257	76
130	78	266	69
150	86	293	79
165	76	295	86
178	82	320	74
203	76	325	78
219	83	350	78

Table VI.—Tungsten Lamp.

Temperature of tube.	Increase in galvanometer deflection over that due to "dark current."	Temperature of tube.	Increase in galvanometer deflection over that due to "dark current."
° C.	mm.	° C.	mm.
22	135	187	141
28	140	203	139
40	138	211	138
58	135	225	136
78	138	240	134
103	136	260	134
117	136	290	132
138	136	320	138
155	138	350	135
171	141		

It will be seen that there was some irregularity in the readings given in the previous Tables, particularly when the mercury arc was used as a source of the radiation of wave-length $\lambda = 10140$ Å.U. This was due to unsteadiness in the voltage from the current supply mains, and in the case of the mercury-arc it was also caused by variations in the energy consumption of the lamp itself. However, from these readings it is clear that as the vapour density increased up to that corresponding to a pressure of one atmosphere,

there was, on the whole, no decrease in the galvanometer deflections. This showed that the amount of radiation of wave-length 10140 Å.U. coming from the source through the absorption tube, was independent of the density of the mercury vapour in the tube, and therefore that the non-luminous mercury vapour did not absorb the radiation of this wave-length.

5. *Absorption Experiments with Luminous Mercury Vapour.*

In order to see whether luminous mercury vapour would absorb radiation of wave-length $\lambda = 10140$ Å.U., a lamp A B, shown in fig. 3, was made up out

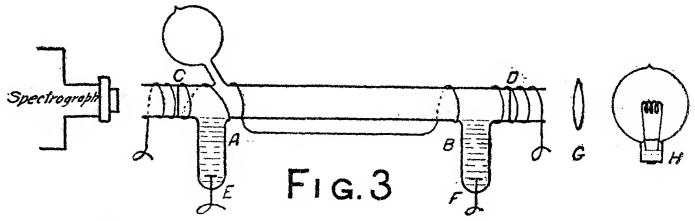


FIG. 3

of pyrex glass. The ends of this lamp were closed by two sealed-in plane parallel plates of pyrex glass, as shown in the diagram. The lamp was partly filled with mercury as indicated, and it was then evacuated and sealed up. By means of two auxiliary heating coils the end-plates at C and D were kept hot and therefore free of any deposit from the mercury vapour. This lamp was placed before the slit of the spectrograph, as shown in the diagram, and the light from the source, H, containing radiation of the wave-length $\lambda = 10140$ Å.U. was focussed with the lens, G, on the slit after passing through the lamp A B. The thalofide cell as in the previous experiments was joined in series with a battery, a galvanometer and a high resistance, and was mounted in the focal plane of the grating so as to receive only the radiation of wave-length $\lambda = 10140$ Å.U. In these experiments, as in those previously described, the quartz mercury arc lamp and the tungsten lamp were used as sources of this radiation.

Readings were taken (1) of the "dark current" deflection when neither the source of light, H, nor the lamp, A B, were in operation; (2) when the pyrex lamp, A B was running with current just sufficient to maintain the arc; (3) when both the lamps, H and A B, were in operation; and (4) immediately after the arc in the pyrex lamp, A B, was extinguished, but while the source of light, H, was kept operating. From these readings it was possible to calculate the percentages of the radiation of wave-length $\lambda = 10140$ Å.U. from the source, H, absorbed by the vapour in the lamp, A B, when the latter was in the luminous state.

A summary of the results obtained from a number of these sets of readings is given in Table VII.

Table VII.

Source of radiation of wave-length $\lambda = 10140$ Å.U.	Increase in deflection over the "dark current" galvanometer deflection due to			Percentage absorption.
	Light from pyrex lamp, mercury arc.	Light from pyrex lamp, mercury arc, and from source H after passing through luminous vapour in A B.	Light from source H after passing through non-luminous vapour in A B.	
	Column I. (mm.)	Column II. (mm.)	Column III. (mm.)	Column IV.
Quartz mercury arc lamp	28·5	109·0	98·0	17·9
	26·0	101·0	92·0	18·5
	26·5	100·5	90·5	18·2
	28·0	86·0	76·0	23·7
			Mean	19·6
Tungsten lamp	11·0	128·0	124·0	5·6
	15·5	141·5	136·5	7·7
	13·0	124·0	120·0	7·5
	20·5	188·5	178·5	6·4
			Mean	6·8

In calculating the percentage absorption given in column IV, the readings in column II were subtracted from the sum of the corresponding ones in columns I and III. These differences were divided by the corresponding numbers in column III, and were taken as measures of the fractional absorptions of the radiation by the luminous vapour. From these fractions the percentage absorptions easily followed.

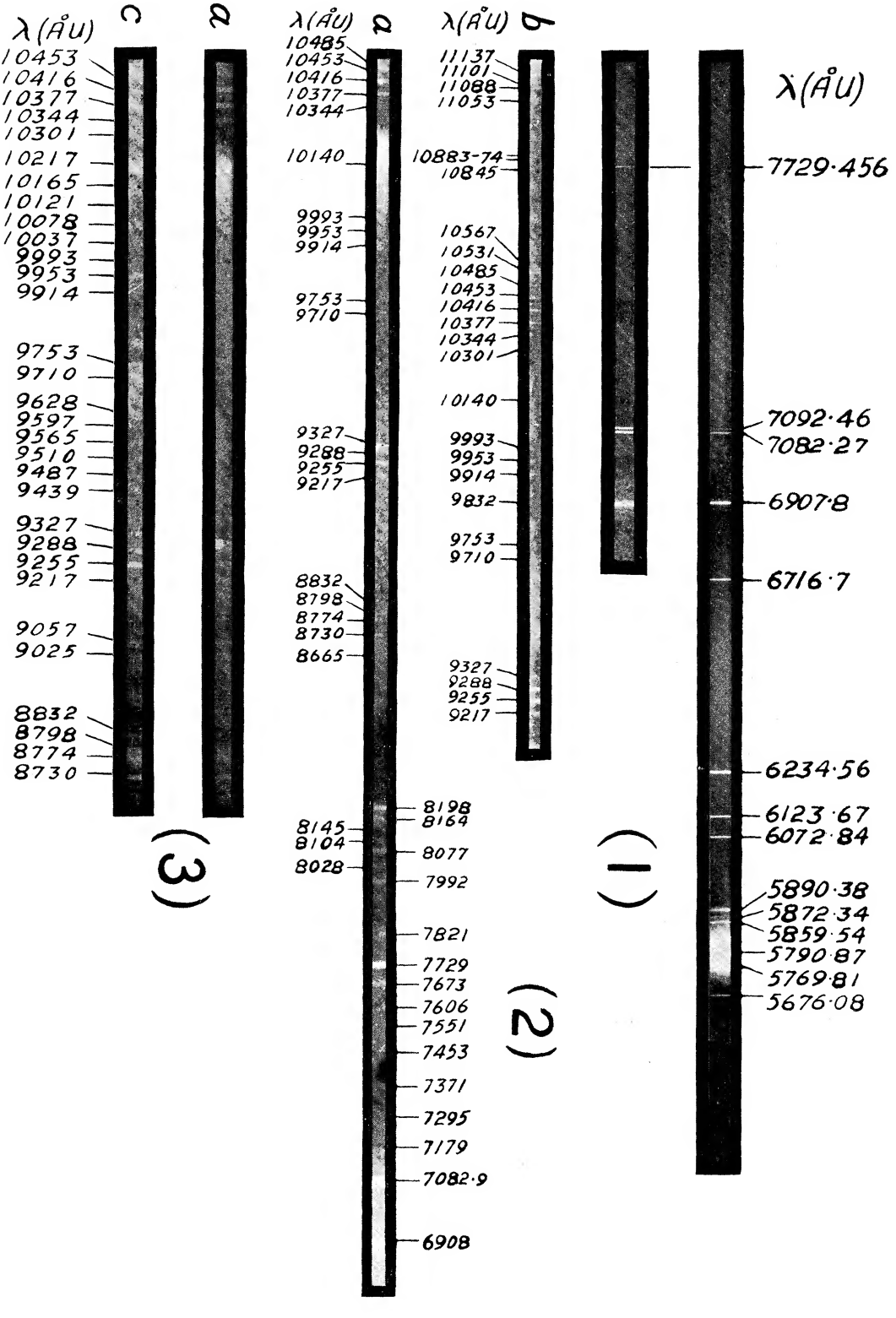
These experiments are interesting examples of the use of thalofide cells, and they will serve to indicate the advantages which are likely to accrue from the extensive use of these cells in the future as radiometers, when measurements of intensity are required to be made in the near infra-red region.

6. *Summary of Results of both Investigations.*

(1) With plates stained with the dye dicyanin, the spectra of a number of the elements have been photographed in the infra-red region. In the case of mercury, the spectrum was photographed up to $\lambda = 11137$ Å.U.

(2) By the photographic method, as well as by the use of thalofide cells, it has been shown that non-luminous mercury vapour does not absorb radiation of the wave-length $\lambda = 10140$ Å.U.

(3) It has been found that slight and scarcely visible deposits of mercury vapour markedly absorb radiation of the wave-length $\lambda = 10140$ Å.U., and this result may possibly afford an explanation of the observations made by Dearle.


λ(Å U)
c
a
10453
10416
10377
10344
10301
10217
10165
10121
10078
10037
9993
9953
9914
9753
9710
9628
9597
9565
9510
9487
9439
9327
9288
9255
9217
9057
9025
8832
8798
8774
8730
(3)
λ(Å U)
a
10485
10453
10416
10377
10344
10140
9993
9953
9914
9753
9710
9327
9288
9255
9217
8832
8798
8774
8730
8665
8198
8164
8145
8104
8077
8028
7992
7821
7729
7673
7606
7551
7453
7371
7295
7179
7082·9
6908
λ(Å U)
b
11137
11101
11088
11053
10883-74
10845
10567
10531
10485
10453
10416
10377
10344
10301
10140
9993
9953
9914
9832
9753
9710
9327
9288
9255
9217
(2)
(1)
λ(Å U)
7729·456
7092·46
7082·27
6907·8
6716·7
6234·56
6123·67
6072·84
5890·38
5872·34
5859·54
5790·87
5769·81
5676·08

(4) By the use of thalofide cells and low-intensity mercury arcs, it has been shown that radiation of the wave-length $\lambda = 10140$ Å.U. may be strongly absorbed by luminous mercury vapour.

(5) From the absence of absorption of radiation of wave-length $\lambda = 10140$ Å.U. by non-luminous mercury vapour, it follows that the atoms of mercury in their ordinary state do not possess a resonance potential of 1·26 volts, corresponding to $\lambda = 10140$ Å.U., in addition to the well-established one of 4·9 volts, corresponding to $\lambda = 2536{\cdot}72$ Å.U.

On the Structure of the Balmer Series Lines of Hydrogen.

By J. C. McLennan, F.R.S., Professor of Physics, and P. Lowe, M.A., University of Toronto.

(Received June 29, 1921.)

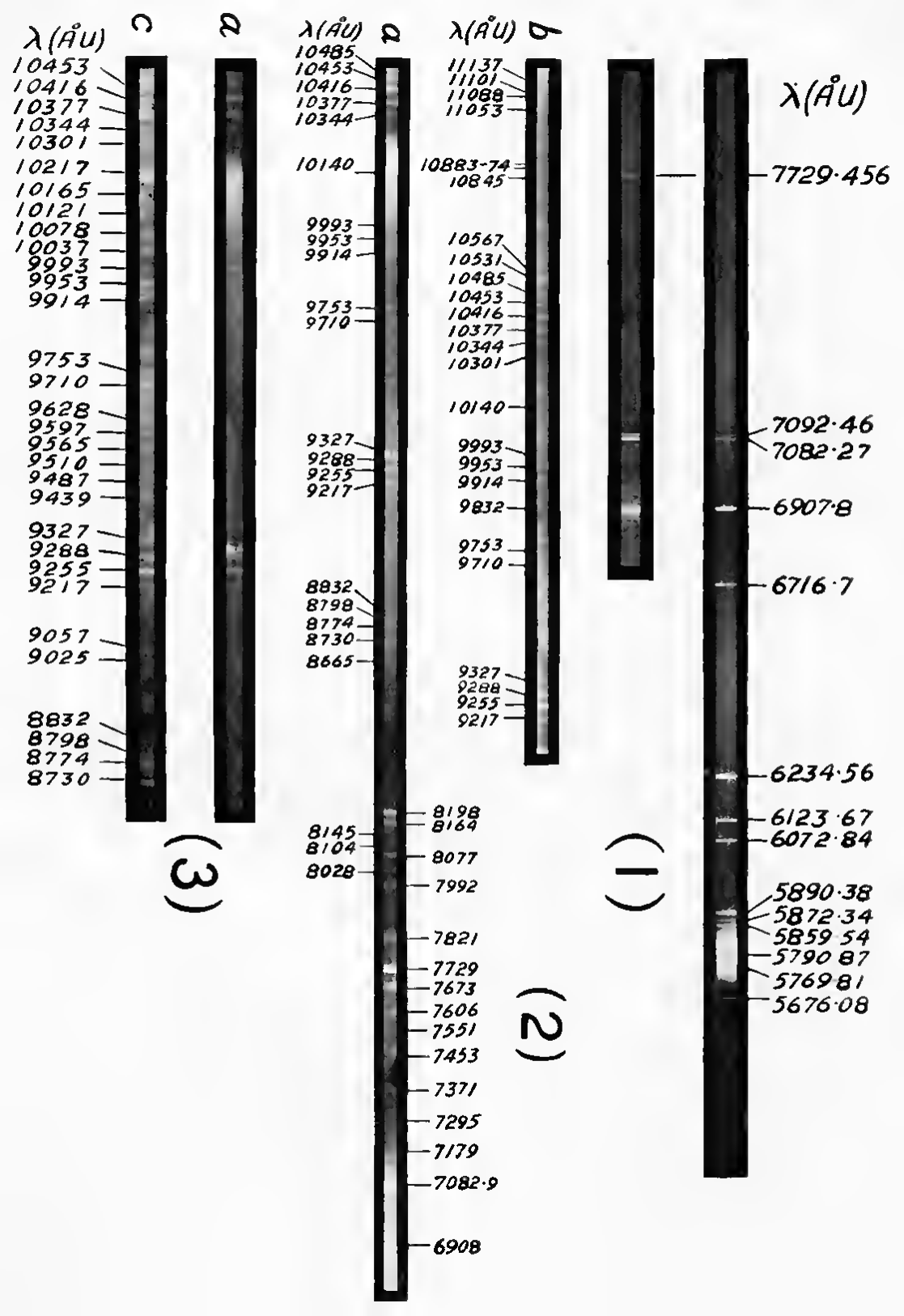
[Plate 8.]

1. *Introduction.*

It is well known that the Balmer series of the hydrogen spectrum, under moderate resolution, consists of doublets. Numerous measurements have been made of the doublet separation for H_α, but only a few of that for H_β. These are as follows:—

H_α.	$\Delta\lambda$ (Å.U.)	$\Delta\nu$ (cm.$^{-1}$).
Michelson and Morley*	0·11	0·253
Ebert†	0·132	0·306
Michelson‡	0·14	0·323
Houstoun§	0·065	0·153
Fabry and Buisson‖	0·132	0·306
Meissner¶	0·124	0·288
Merton and Nicholson**	0·132	0·306
Merton††	0·145	0·34
Gehrcke and Lau‡‡	0·126	0·293

* Michelson and Morley, 'Phil. Mag.,' vol. 24, p. 46 (1887).
† Ebert, 'Wied. Ann.' (N.P.), vol. 43, p. 800 (1891).
‡ Michelson, 'Bur. Int. des Poids et Mesures,' vol. 11, p. 139 (1895).
§ Houstoun, 'Phil. Mag.,' vol. 7, p. 460 (1904).
‖ Fabry and Buisson, 'C. R.,' vol. 154, p. 1501 (1912).
¶ See Paschen, 'Ann. der Phys.,' vol. 50, p. 933 (1916).
** Merton and Nicholson, 'Roy. Soc. Proc.,' A, vol. 93, p. 28 (1917).
†† Merton, 'Roy. Soc. Proc.,' A, vol. 87, p. 307 (1920).
‡‡ Gehrcke and Lau, 'Phys. Zeit.,' vol. 21, p. 634 (1920).


λ(Å U)
c
a
10453
10416
10377
10344
10301
10217
10165
10121
10078
10037
9993
9953
9914
9753
9710
9628
9597
9565
9510
9487
9439
9327
9288
9255
9217
9057
9025
8832
8798
8774
8730
(3)
λ(Å U)
a
10485
10453
10416
10377
10344
10140
9993
9953
9914
9753
9710
9327
9288
9255
9217
8832
8798
8774
8730
8665
8198
8164
8145
8104
8077
8028
7992
7821
7729
7673
7606
7551
7453
7371
7295
7179
7082·9
6908
λ(Å U)
b
11137
11101
11088
11053
10883-74
10845
10567
10531
10485
10453
10416
10377
10344
10301
10140
9993
9953
9914
9832
9753
9710
9327
9288
9255
9217
(2)
(1)
λ(Å U)
7729·456
7092·46
7082·27
6907·8
6716·7
6234·56
6123·67
6072·84
5890·38
5872·34
5859 54
5790 87
5769 81
5676·08